



Conceptualising Assembly 4.0 through the Drone Factory

Downloaded from: <https://research.chalmers.se>, 2023-05-05 15:45 UTC

Citation for the original published paper (version of record):

Fasth Berglund, Å., Åkerman, M., Li, D. et al (2019). Conceptualising Assembly 4.0 through the Drone Factory. IFAC-PapersOnLine, 52(13): 1525-1530.

<http://dx.doi.org/10.1016/j.ifacol.2019.11.416>

N.B. When citing this work, cite the original published paper.

Conceptualising Assembly 4.0 through the drone factory

Å. Fast-Berglund*, M. Åkerman
D. Li and Omkar Salunkhe

*Chalmers University of Technology, SE-412 965; e-mail: asa.fasth@chalmers.se.

Abstract: This paper aims to discuss the complexity of designing an assembly system according to industry 4.0. This is done by introducing the drone factory as a learning facility at the digital innovation hub (SIILab). The paper discusses the areas of Operator-Organisation, Operator-Technologies, Technologies-Product and Product-Organisation in a current state and information support subsystem, IIoT architecture and hardware in the assembly 4.0 context.

Keywords: Assembly 4.0, Industry 4.0, IIoT, Drone factory

1. INTRODUCTION

When designing an assembly system, there is a lot of areas that need to be considered. A mass customised final assembly system has an increased product variant compared to the earlier stages within the production system [ref]. More agile and responsive assembly strategies needs to be developed in order to meet the costumers needs (ElMaraghy and ElMaraghy, 2016). The physical and cognitive Level of Automation (LoA) is also lower in final assembly (Fast-Berglund et al., 2016) than in earlier stages of the manufacturing system. Adoptable and reconfigurable systems have been used a lot in highly automated robot lines (Valente and Carpanzano, 2011) but more seldom in final assembly. A study conducted in Sweden shows that over 95 percent of the final assembly tasks are performed with help of a human operator (so called manual and semi-automatic tasks). Furthermore, human-centred approach when it comes to automation is rarely seen. Human-centred automation can be described as 'automation designed to work cooperatively with human operators, this emphasizes that automation functionality should be designed to support human performance and human understanding of the system (Billings, 1996). This means that both cognitive and physical automation solutions need to be developed and implemented. Information and support systems like instructions, planning and balancing also needs to increase within final assembly. Since 2009 (var det inte 2005?) when the introduction of a smart factory appeared (Zuehlke, 2009) and later on when industry 4.0 was coined, different solutions has been suggested. Different frameworks (Bortolini et al., 2017, Thramboulidis et al., 2018) and methodologies (Stich et al., 2018) have been presented but most of them are technology driven towards increasing ICT level, digitalisation, autonomous planning and control and multi-agent systems. A lot of these strategies within smart factory are still technology centred (Kusiak, 2018), for example the nine enabling technologies mentioned by (Bortolini et al., 2017); Collaborative robots (Tsarouchi et al., 2016), Cyber-physical systems, IIoT, big data etc. Often it is still too complex for

industrial companies to understand were to start (Stefan et al., 2018) and how to integrate all dimensions and all technologies (Qin et al., 2016).

There are not many publications focusing on implementing industry 4.0 technologies within the final assembly. Some reasons can be that it is a complex environment (Mattsson et al., 2016) with a lot of variants, manual labour and

We believe that to build a sustainable and well functional assembly system, the operators need to be involved from the start which means the both the operators themselves and the organisation need to be prepared for the new paradigm. Often the first advancement attempts fail due to a lack of knowledge of the interdependencies between the three dimensions of the sociotechnical approach (technology, organization, employees) (Stefan et al., 2018). The concept of Operator 4.0 (O4) (Romero, 2016) is an important resource in order to fulfil the assembly 4.0 strategy. O4 is defined as "a smart and skilled operator who performs not only – 'cooperative work' with robots – but also – 'work aided' by machines as and if needed – by means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation towards "human-automation symbiosis work systems". Furthermore, an understanding of the relation between the Information Technology (IT) and Information Support (IS) system is vital (FAST-BERGLUND et al., 2018b) in order to create a system with high information quality, personalised adopted information and a smart agent-based planning system (Weichhart et al., 2018) that can provide the right amount of information needed to perform routine and non-routine tasks and to plan the resource allocation between cobots and human operators.

The aim of this paper is to describe how industry 4.0 has been implemented in a learning factory to create a flexible and sustainable assembly system. The learning factory is contextualized in the drone factory.

2. THE DRONE FACTORY

The product and assembly layout have been developed during 2018 to become assembly 4.0. In order to achieve this, not only enabling technologies (Bortolini et al., 2017) has been studied but also enabling operator skills (Romero et al., 2018) and enabling organisation management. The industrie 4.0 maturity index, developed by Acatech in 2016 (Stich et al., 2018) with the four structural areas e.g. Resources, Information systems, Organisational structure and Culture is used to get a broad implementation in the different areas. Figure 1 shows a combination of the maturity index areas and some enabling technologies and areas that is important when designing a future assembly system.

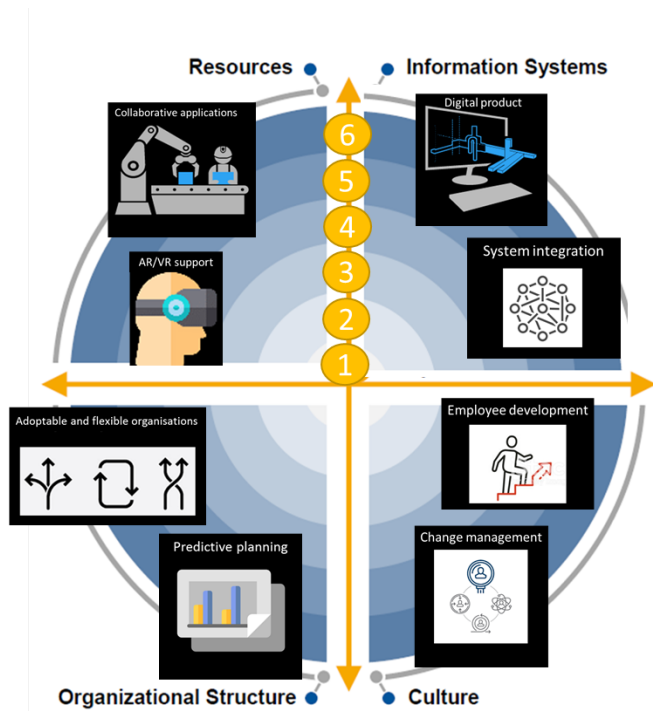


Fig. 1. Combining maturity index with the enabling technologies

The enabling technologies is used in different part of the system. There is still a lot of focus on IIoT and cyber-physical systems (Bortolini et al., 2017) when implementing industry 4.0. Hence, there is a trend towards increased interest towards collaboration and interconnections (Hermann et al., 2016). The resources in current assembly are still mostly manual. The sections below will bring up the enabling technologies connected to the four focus areas adopted from (Stich et al., 2018) to become more assembly 4.0.

2.1 Resources – Flexible automation

There is no uncomplicated way to make automation human-oriented that is applicable across all tasks and types of work in final assembly. Different processes and domains may put different emphasis on precision, stability and/or speed of production. Each case requires its own considerations of which type of automation is the most appropriate, and how

control and interaction can be enhanced and facilitated via a proper design of the automation involved (Hollnagel, 2003). The drone factory focuses on the interaction and cooperation between humans and cobots to create collaborative applications in final assembly tasks. According to (Boesl and Liepert, 2016) the second revolution of robots are the collaborative robots. Several cobots are tested (Fast-Berglund et al., 2016) to see the differences in user-friendliness, interaction and interoperability to other systems. The third revolution is moving flexible robots. In the drone factory there are different support systems, both when it comes to carrier and content of information (Fast-Berglund et al., 2014). Extended technologies (xR technologies) (Fast-Berglund et al., 2018a), can be triggered when the operator needs the information. Assembly instructions can be chosen to be displayed using different information carriers (smart pads, softbots, glasses, screens, sensors etc.) containing different information content (text, picture, movies, AR, voice etc.). Combining these different carriers and content put high requirements of the ability to create flexible information flows through the system.

The physical work environment in the assembly area consists of several work centres (stations) connected through a conveyor system to transport the drone and its components, illustrated in Figure 2.

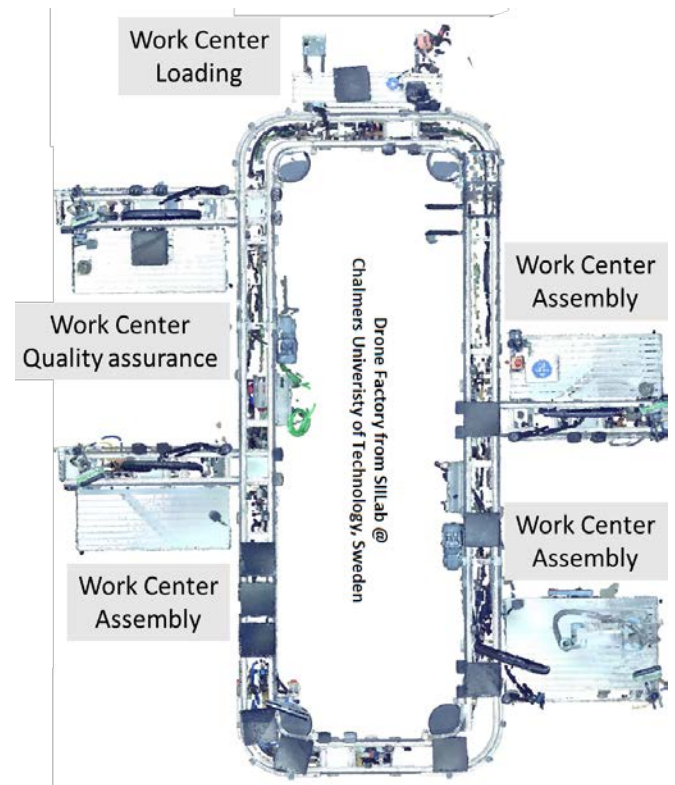


Fig. 2. The physical environment of the drone factory; Flexible work centers with adoptable levels of Automation

The conveyor system with connected work centres operates with complete flexibility in terms of location and activity. This means that any work centre can be placed at any position along the conveyor, or anywhere at the factory, as an agile plug and produce system (Arai et al., 2000). There is no

limit to what resources can be connected to a work centre, but there are two types of base modules to build on. The simplest one is completely virtual, meaning it only exists as a digital model but with the possibility to attach other tangible systems. The other has its own small conveyor for automatic load/unload of pallets and automatic adjustment of the table height, which can be connected to operator and/or current task. All these automation concepts require a solid digital architecture with the right types of system and IoT orchestration.

2.2 Information systems – IT architecture

Industry 4.0 is defined with a requirement of integrating organisations in three aspects. Horizontal integration to interconnect different business functions (or organizational units), vertical integration to allow data exchange across operational aspects, and end-to-end integration to simplify interactions across the supply chain. These three aspects meet in the production operation phase and this is especially noticeable in the assembly process. This is because final assembly often has high requirements in terms of timely deliveries while being dependant on both design- and previous manufacturing processes as well as logistics the information systems involved are usually more than practical.

Interoperability is the means to solve *system integration* issues, and it is a vital component to implementing Industry 4.0 (Thoben et al., 2017) and for a dynamic assembly system (Åkerman et al., 2016). To maintain flexibility, interoperable systems do not fully integrate entities with hard coupled connections. Instead, a more federated approach is preferred where communication is managed more dynamically (Chen and Daclin, 2006). A great way of achieving this is by adopting different types of middleware and Internet of Things (IoT) platforms, as well as utilising well defined

communication protocols and standards e.g. HTTP, MQTT. But interoperability does not only concern data transfer between systems. It is also important that users understand the data in form of information (Åkerman and Fast-Berglund, 2018). These concepts also goes hand in hand with the four design principles of industry 4.0: interconnection, information transparency, decentralized decision, and technical assistance (Hermann et al., 2016).

The drone factory is built around a modular and event-driven architecture [ref. 2018, Åkerman, Modularized assembly system: A digital innovation hub for the Swedish

Smart Industry] centralized around PTC's IIoT-platform Thingworx. The Drone factory uses software from PTC to create a *digital twin* of both product and production system to enable an adoptable and proactive communication throughout the chain from product development to operators in final assembly, this is illustrated in fig. 2. PLM and MBD standards has been used together as a knowledge management tool solve the semantic interoperability problem of heterogeneous data and to improve the capabilities of technology intensive organisations to monitor and respond to technological and product changes (Raza et al., 2009). In order to do that the system must be integrated both horizontally and vertically across different systems and organisations (Bauernhansl et al., 2014). For the organisation such integration may lead to better collaboration between different roles and functions (Schuh et al., 2014). In the drone factory software from PTC will be used for CAD, PLM and AR application as a first step. Figure 3 illustrates how different types of software and specific implementations are used in the drone factory to create a digital twin of both product and factory. This complete digital model allows for automated planning and preparation for the operations phase e.g. assembly instructions based on the original 3D models.

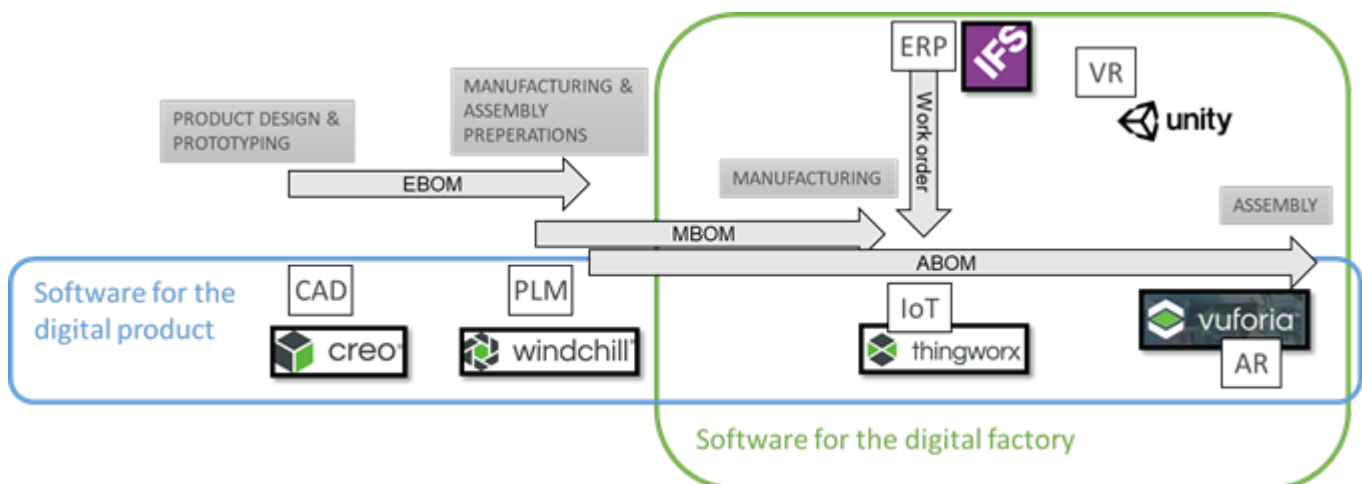


Figure 3: The digital environment of the factory; Software used to create the digital product and the digital factory.

2.3 Organisation structure – Knowledge sharing

It is vital that operators and the organisation share knowledge about the assembly process. Sharing knowledge can create a better way to work, continuous improvements, and a feeling of empowerment among the operators (Leach et al., 2003). It is also important that they can report or store that knowledge into an information system (Li et al., 2016). For this, trust within the organisation is vital, motivated operators (Jiacheng et al., 2010) and a high quality information support system.

The Information support system (ISS) plays an important role in the assembly system and will provide the operator with high quality information needed. Information systems strategy (ISS) have three important activities defined as 'activities directed toward (1) recognising organisational opportunities for using information technology, (2) determining the resource requirements to exploit these opportunities, (3) and developing strategies and action plans for realising these opportunities and for meeting the resource needs' (Boynton and Zmud, 1987). In assembly 4.0, agent based systems will be more adopted for both planning (Weichhart et al., 2018, Weichhart et al., 2016) support (Kaptein et al., 2017) and motivation (Fast-Berglund et al., 2018c). To create an adoptive and flexible work environment, cognitive automation also needs to be further developed. The fourth revolution is social agents or AI robots e.g. increased cognitive automation. Six areas have been identified as critical aspects when designing an information support system (Johansson et al., 2018); IT challenges, Process challenges, Information availability, Assembly process disruptions, Technology and process control and Assembly work instructions Context-aware information requires a system that acknowledges the need of individuals and can provide the right information at the right place in the right time (Kagermann et al., 2013).

2.4 Culture – trust and motivation in the organisation

A human-centred culture towards development of production systems have positive effects on continuous improvement efforts (Lam et al., 2015). By promoting and empowering (Mattsson et al., 2014) the operators, an inter-personal trust within the organization can be built, which is important for implementing changes (Hoffman et al., 2013). This trust between people is important for sharing knowledge with each other (Riege, 2005), and is also an important contributor towards the social dimension of sustainable development.

3. CONCLUSIONS

Implementing assembly 4.0 is a complex task that requires a lot of different competences. It is hard to realise the depth and complexity before seeing it in practise. We believe that even though our drone factory is a learning factory in a lab environment it still shows the complexity of implementing assembly 4.0. The industry often have legacy of both information systems and hard-ware that is hard to ignore. Building a decentralised and event driven system is one opportunity to be able to integrate old systems with new and start the journey towards assembly 4.0.

Acknowledgement

This research work is funded by the Stena Industry Innovation Lab (SIILab), co-funded within the Production 2030 and Vinnova

REFERENCES

- ARAI, T., AIYAMA, Y., MAEDA, Y., SUGI, M. & OTA, J. 2000. Agile Assembly System by "Plug and Produce". *CIRP Annals*, 49, 1-4.
- BAUERNHANS, P. D. T., DIEGNER, D. B., DIEMER, J., DÜMMLER, D. M., ECKERT, P. D. C., HERFS, D. W., HEYN, D. H., HILGER, C., HOMPEL, P. D. M. T., KALHOFF, J., KUBACH, D. U., LIGGESMEYER, P. D. P., LOEWEN, D. U., NEBEL, P. D.-I. W., QUETSCHLICH, M., STEFFENS, E.-J., SOWIE, D. T. S. & SPAETH, F. D. B. 2014. Industrie 4.0 - Whitepaper FuE-Themen.
- BILLINGS, C. E. 1996. *Aviation automation: the search for a human-centered approach*.
- BOESL, D. B. O. & LIEPERT, B. 4 Robotic Revolutions - proposing a holistic phase model describing future disruptions in the evolution of robotics and automation and the rise of a new Generation 'R' of Robotic Natives. 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 9-14 Oct. 2016 2016. 1262-1267.
- BORTOLINI, M., FERRARI, E., GAMBERI, M., PILATI, F. & FACCIO, M. 2017. Assembly system design in the Industry 4.0 era: a general framework. *IFAC-PapersOnLine*, 50, 5700-5705.
- BOYNTON, A. C. & ZMUD, R. W. 1987. Information technology planning in the 1990's: directions for practice and research. *MIS Q.*, 11, 59-71.
- CHEN, D. & DACLIN, N. 2006. Framework for enterprise interoperability. *Proc. of IFAC Workshop EI2N*, 77-88.
- ELMARAGHY, H. & ELMARAGHY, W. 2016. Smart Adaptable Assembly Systems. *Procedia CIRP*, 44, 4-13.
- FAST-BERGLUND, Å., GONG, L. & LI, D. 2018a. Testing and validating Extended Reality (xR) technologies in manufacturing. *Procedia Manufacturing*, 25, 31-38.
- FAST-BERGLUND, Å., LI, D. & ÅKERMAN, M. Creating strategies to improve the use of IT- and IS-system in final assembly. In: CASE, P. T. A. K., ed. 16th international conference on manufacturing research, 2018b Skövde, Sweden.
- FAST-BERGLUND, Å., PALMKVIST, F., NYQVIST, P., EKERED, S. & ÅKERMAN, M. 2016. Evaluating Cobots for Final Assembly. *Procedia CIRP*, 44, 175-180.
- FAST-BERGLUND, Å., THORVALD, P., BILLING, E., PALMKVIST, A., ROMERO, D. & WEICHHART, G. Conceptualizing Embodied Automation to Increase Transfer of Tacit knowledge IEEE International Conference on Intelligent Systems (IS), 2018c Madeira.

- FAST-BERGLUND, Å., ÅKERMAN, M., KARLSSON, M., HERNÁNDEZ, V. G. & STAHR, J. 2014. Cognitive Automation Strategies – Improving Use-efficiency of Carrier and Content of Information. *Procedia CIRP*, 17, 67-70.
- HERMANN, M., PENTEK, T. & OTTO, B. Design Principles for Industrie 4.0 Scenarios. 2016 49th Hawaii International Conference on System Sciences (HICSS), 5-8 Jan. 2016 2016. 3928-3937.
- HOFFMAN, R. R., JOHNSON, M., BRADSHAW, J. M. & UNDERBRINK, A. 2013. Trust in Automation. *IEEE Intelligent Systems*, 28, 84-88.
- HOLLNAGEL, E. 2003. *Handbook of Cognitive Task Design*, Mahwah, New Jersey, Routledge.
- JIACHENG, W., LU, L. & FRANCESCO, C. A. 2010. A cognitive model of intra-organizational knowledge-sharing motivations in the view of cross-culture. *International Journal of Information Management*, 30, 220-230.
- JOHANSSON, P. E. C., MALMSKÖLD, L., FAST-BERGLUND, Å. & MOESTAM, L. 2018. Enhancing Future Assembly Information Systems – Putting Theory into Practice. *Procedia Manufacturing*, 17, 491-498.
- KAGERMANN, H., WAHLSTER, W. & JOHANNES, H. 2013. Recommendations for implementing the strategic initiative Industrie 4.0.
- KAPTEIN, F., BROEKENS, J., HINDRIKS, K. & NEERINCX, M. Self-explanations of a cognitive agent by citing goals and emotions. 2017 Seventh International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), 23-26 Oct. 2017 2017. 81-82.
- KUSIAK, A. 2018. Smart manufacturing. *International Journal of Production Research*, 56, 508-517.
- LAM, M., O'DONNELL, M. & ROBERTSON, D. 2015. Achieving employee commitment for continuous improvement initiatives. *International Journal of Operations & Production Management*, 35, 201-215.
- LEACH, D. J., WALL, T. D. & JACKSON, P. R. 2003. The effect of empowerment on job knowledge: An empirical test involving operators of complex technology. *Journal of Occupational and Organizational Psychology*, 76, 27-52.
- LI, D., FAST-BERGLUND, Å., GULLANDER, P. & RUUD, L. Identifying Improvement Areas in Production Planning Meetings by Assessing Organisation and Information Systems at a Small Production Company. Swedish Production Symposium, 2016 Lund, Sweden.
- MATTSSON, S., KARLSSON, M., FAST-BERGLUND, Å. & HANSSON, I. 2014. Managing Production Complexity by Empowering Workers: Six Cases. *Procedia CIRP*, 17, 212-217.
- MATTSSON, S., TARRAR, M. & FAST-BERGLUND, Å. 2016. Perceived production complexity – understanding more than parts of a system. *International Journal of Production Research*, 54, 6008-6016.
- QIN, J., LIU, Y. & GROSVENOR, R. 2016. A Categorical Framework of Manufacturing for Industry 4.0 and Beyond. *Procedia CIRP*, 52, 173-178.
- RAZA, M. B., KIRKHAM, T., HARRISON, R. & REUL, Q. 2009. Knowledge Based Flexible and Integrated PLM System at Ford *Journal of Information & Systems Management*.
- RIEGE, A. 2005. Three-dozen knowledge-sharing barriers managers must consider. *Journal of Knowledge Management*, 9, 18-35.
- ROMERO, D., MATTSSON, S., FAST-BERGLUND, Å., WUEST, T., GORECKY, D. & STAHR, J. Digitalizing Occupational Health, Safety and Productivity for the Operator 4.0. 2018 Cham. Springer International Publishing, 473-481.
- ROMERO, D., STAHR, J., WUEST, T., NORAN, O., BERNUS, P., FAST-BERGLUND, Å. AND GORECKY, D 2016. TOWARDS AN OPERATOR 4.0 TYPOLOGY: A HUMAN-CENTRIC PERSPECTIVE ON THE FOURTH INDUSTRIAL REVOLUTION TECHNOLOGIES. *International Conference on Computers & Industrial Engineering CIE* 46.
- SCHUH, G., POTENTE, T., VARANDANI, R., HAUSBERG, C. & FRÄNKEN, B. Collaboration Moves Productivity To The Next Level. 2014 2014.
- STEFAN, L., THOM, W., DOMINIK, L., DIETER, K. & BERND, K. 2018. Concept for an evolutionary maturity based Industrie 4.0 migration model. *Procedia CIRP*, 72, 404-409.
- STICH, V., GUDERGAN, G. & ZELLER, V. Need and Solution to Transform the Manufacturing Industry in the Age of Industry 4.0 – A Capability Maturity Index Approach. 2018 Cham. Springer International Publishing, 33-42.
- THOBEN, K.-D., WIESNER, S. & WUEST, T. 2017. “Industrie 4.0” and Smart Manufacturing – A Review of Research Issues and Application Examples. *Int. J. of Automation Technology*, 11, 4-16.
- THRAMBOULIDIS, K., KONTOU, I. & VACHTSEVANOU, D. C. 2018. Towards an IoT-based Framework for Evolvable Assembly Systems. *IFAC-PapersOnLine*, 51, 182-187.
- TSAROUCHI, P., MAKRIS, S. & CHRYSSOLOURIS, G. 2016. Human-robot interaction review and challenges on task planning and programming. *International Journal of Computer Integrated Manufacturing*, 29, 916-931.
- VALENTE, A. & CARPANZANO, E. 2011. Development of multi-level adaptive control and scheduling solutions for shop-floor automation in reconfigurable manufacturing systems. *CIRP Annals*, 60, 449-452.
- WEICHHART, G., FAST-BERGLUND, Å., ROMERO, D. & PICHLER, A. An Agent- and Role-based Planning Approach for Flexible Automation of Advanced Production Systems. IEEE 9th International Conference on Intelligent Systems, 2018 Maderia Island, Portugal.

- WEICHHART, G., GUÉDRIA, W. & NAUDET, Y. 2016. Supporting interoperability in complex adaptive enterprise systems: A domain specific language approach. *Data & Knowledge Engineering*, 105, 90-106.
- ZUEHLKE, D. 2009. SmartFactory – A Vision becomes Reality. *IFAC Proceedings Volumes*, 42, 31-39.
- ÅKERMAN, M. & FAST-BERGLUND, Å. Interoperability for Human-Centered Manufacturing. *In*: DEBRUYNE, C., PANETTO, H., WEICHHART, G., BOLLEN, P., CIUCIU, I., VIDAL, M.-E. & MEERSMAN, R., eds. On the Move to Meaningful Internet Systems. OTM 2017 Workshops, 2018//2018 Cham. Springer International Publishing, 76-83.
- ÅKERMAN, M., FAST-BERGLUND, Å. & EKERED, S. Interoperability for a Dynamic Assembly System. *Procedia CIRP*, 2016. 407-411.